Diffuse and Spark Discharges at High Overvoltages in High Pressure Air, Nitrogen and SF_6

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Abstract

The formation of runaway electron preionized diffuse discharges (REP DDs) and the generation of a supershort avalanche electron beam (SAEB) in air, nitrogen and SF_6 in an inhomogeneous electric field was investigated. Dynamics of the discharge plasma radiation from the different discharge gap regions in the gas pressure range 0.05-0.7 MPa was established. Waveforms of the voltage pulses across the gap, and as well current through gap pulses and SAEB was registered with a time resolution of ~0.1 ns.

Keywords

RADAN-220 Pulser; Runaway Electrons (RAE); Runaway Electrons Preonized Diffuse Discharge (REP DD); Supershort Avalanche Electron Beam (SAEB)

Introduction

Discharges in an inhomogeneous electric field are widely distributed in the earth's atmosphere. Formed in laboratory pulse discharges in the inhomogeneous electric field at high pressure are investigating by different scientific groups (see reference, for example). Since the late sixties of the last century it is known, about possibility of formation of diffuse discharges in atmospheric pressure air without additional ionization source. Features of such discharge are generation in the discharge gap of RAE and X-ray due to interaction of RAE with anode and gas particles. Depending on distance between the electrodes, amplitude and duration of voltage pulses, as well another parameters a corona discharge is initially formed near the electrode with a small radius of curvature in different gases. Then, the corona discharge transforms to the REP DD, due to increasing of amplitude of voltage pulse, e.g. Further increasing of an amplitude of voltage pulse leads to REP DD constriction. In this case, emission intensity of a spark discharge plasma may be more than emission intensity of the corona discharge and the REP DD one. Similar changes of discharge type are observed in a pulse-periodic mode also. We assume, that a similar dynamics takes place during the lightning formation in the earth's atmosphere and in a corona streamer and a leader head. However, the properties of the initial stage of pulse discharges in inhomogeneous electric fields have not been investigated in deteil. Primarily, it is connected with a short duration of RAE beam and caused by it X-ray. Due to RAE and X-ray emisson a generation of various forms of discharge are possible at high pressure. For example, only two scientific groups reported about the registration of RAE beam in SF_6 at pressure of 0.1 MPa or higher. However, in references the time resolution was no better than ~3,5 ns. While the duration of SAEB is ~100 ps in air, nitrogen and SF_6 at atmospheric pressure. The use of term SAEB for the RAE beam that is registered behind the foil was proposed in reference.

Objective of this work to study the initial stage of discharge in an inhomogeneous electric field at high pressure of air, nitrogen and SF_6. This work is continuation of studies that carried out in references. Main attention in this paper was paid to registration of the discharge plasma radiation from different discharge gap regions, as well the voltage across the discharge gap, current through the gap at breakdown.

Furthermore, SAEB was registered behind the anode foil at negative polarity of RADAN-220 pulser in a wide pressure range.

Experimental Setup and Measurements

Experiments were performed on unique setup. This setup was designed to study discharges and RAE generation in different gases and made it possible to measure several relevant parameters simultaneously. Thus, the setup allowed us to register the voltage across the discharge gap, current through the gap, SAEB current and radiation of a discharge plasma from different gap regions in a single pulse. Moreover, the polarity of RADAN-220 pulser in the setup could be either negative or positive.

The block-diagram of the experimental setup are presented in Fig. 1. The voltage pulse produced by the RADAN-220 pulser applied through a short transmission line (5) to an electrode with small radius of curvature (7). In one case the potential electrode (7) was made of 100-μm-thick stainless steel foil twisted into a tube (Ø ~6mm), and the grounded electrode was a plate which was located at a distance of 13 mm from the edge of the potential electrode. Otherwise both the potential and grounded electrodes were made of razorblades of thickness of 100 μm and have a length 19 and 38 mm, respectively. Gap distance was the same. The voltage was measured with a capacitive divider (6) located at the end of the transmission line (5). The pulser was connected to the gap via the short transmission line (5) whose wave impedance was several times higher than that of the RADAN-220 pulser, making it possible to increase the voltage pulse amplitude in the gap up to ~340 kV. The voltage pulse duration at a matched load was ~2 ns, and the pulse rise time in the transmission line was ~0.5 ns. The current through the gap was measured by a shunt (8) made of chip resistors. The chip resistors were connected in series with the flat electrode (9) and were uniformly located at its circumference. SAEB current was measured by a collector (10) simultaneously with the discharge current and voltage pulse in the gap at the negative polarity of the voltage pulse. For the registration of SAEB current the anode (9) made of AlMg diameter of 1 cm and thickness of 50 μm was used. It was reinforced by a metal grid with transparency 14 %. The collector (10) was located downstream of the anode foil. The discharge chamber was filled with air, nitrogen or SF_6. The discharge chamber was pumped with a forevacuum pump. The pressures of gases ranged from 0.01 to 0.7 MPa. Due to a lens (3) 2 times magnified discharge images are formed on screens (2) with 1 mm width split. Thus, the plasma radiation from different discharge gap regions was selected. When the plasma filled this region, the photodiode PD025 (cathode is LNS20, Photek company. The rise time is ~80 ps) (1) recorded the radiation from this region. The spatial resolution of the system for measuring the radiation from each region of the discharge gap was ~ 1 mm in the direction of the longitudinal gap axis. The radiation was measured from the cathode, middle of the gap and anode regions. Signals from the capacitive voltage divider, shunt, collector, and photodiode were recorded with Tektronix DPO70604 digital oscilloscope (6 GHz, 25 GS/s) (11). The detectors were connected to the oscilloscope via RadioLab 5D-FB PEEG coaxial pulse cables with standard N-type connectors and Barth Electronics 142-NM attenuators with a bandwidth up to 30 GHz. The integral emission spectra were recorded by a spectrometer EPP-2000C (Stellar-Net Inc.). The discharge plasma glowing was photographed by a Sony - A100.

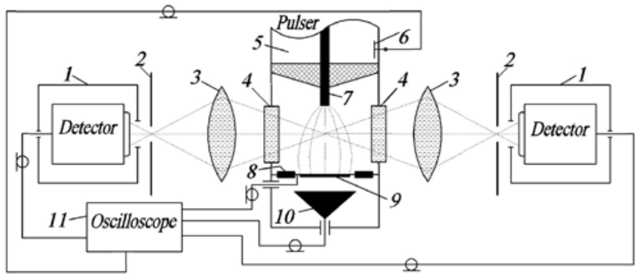

FIG. 1 BLOCK-DIAGRAM OF EXPERIMENTAL SETUP: 1 – PHOTODETECTOR PD025 IN METAL BOX; 2 – SCREEN WITH SPLIT; 3 – LENS; 4 – SIDE WINDOW; 5 – TRANSMISSION LINE OF RADAN-220 PULSER; 6 – CAPACITIVE VOLTAGE DIVIDER; 7 – HIGH VOLTAGE ELECTRODE; 8 – CURRENT SHUNT; 9 - GROUND ELECTRODE MADE OF THIN FOIL; 10 – COLLECTOR; 11 – OSCILLOSCOPE

Experimental Results

Owing to the created experimental setup a measurements of discharge characteristics and registration of plasma emission from different discharge gap regions were carried out with the time resolution no worse than ~0,1 ns. Both polarities of RADAN-220 pulser were used. The grounded and potential electrodes were flat and tubular, respectively. The discharge at the “blade-blade” electrodes configuration was studied as well. Typical waveforms of recorded pulses with a tubular cathode are shown in Fig. 2 and 3 in nitrogen and air at pressure of 0.3 MPa. In nitrogen the REP DD was formed at both polarity and gap distance of 13 mm. (Fig. 4). In air at

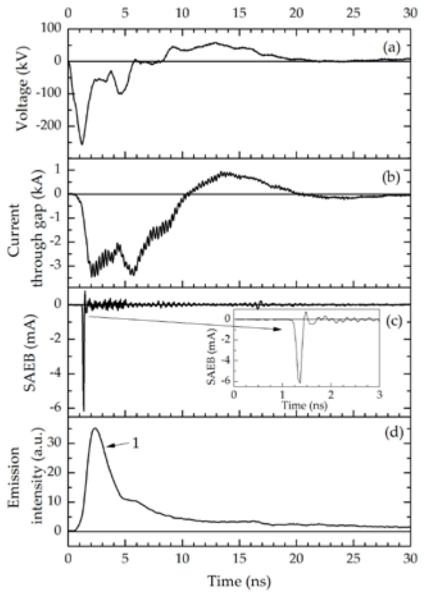

FIG. 2 WAVEFORMS OF VOLTAGE PULSES (a), CURRENT THROUGH THE GAP (b), SAEB CURRENT (c) AND DISCHARGE PLASMA RADIATION (d). NITROGEN PRESSURE IS 0.3 MPa. THE PEAK OF RADIATION (1) IS RADIATION OF DIFFUSE DISCHARGE PLASMA

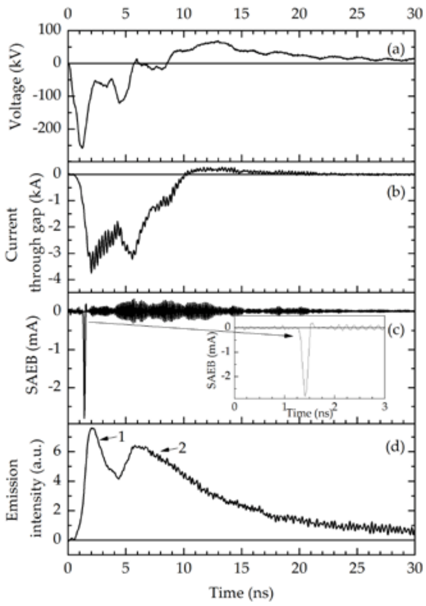

FIG. 3 WAVEFORMS OF VOLTAGE PULSES (a), CURRENT THROUGH THE GAP (b), SAEB CURRENT (c) AND DISCHARGE PLASMA RADIATION (d). AIR PRESSURE IS 0.3 MPa. THE PEAK OF RADIATION (1) IS RADIATION OF DIFFUSE DISCHARGE PLASMA AND THE PEAK OF RADIATION (2) IS RADIATION OF SPARK DISCHARGE PLASMA

the same condition, the RED DD was constricted. The peak of radiation (1) in Fig. 2 (d) and Fig. 3 (d) is a radiation of a diffuse discharge stage. The main contribution to this radiation is given by the nitrogen second positive system. The peak (2) in Fig. 3 (d) corresponds to the radiation of a spark. The main contribution to this radiation is given by a wideband continuum, and lines and bands of gases ions also. REP DD formation (Fig. 4) was provided by SAEB generation, Fig 2 (c) and Fig. 3 (c), and by X-ray radiation which was registered at an initial stage of breakdown. From Fig. 2 and Fig. 3 it is seen, that SAEB is generated at the front of current pulse.

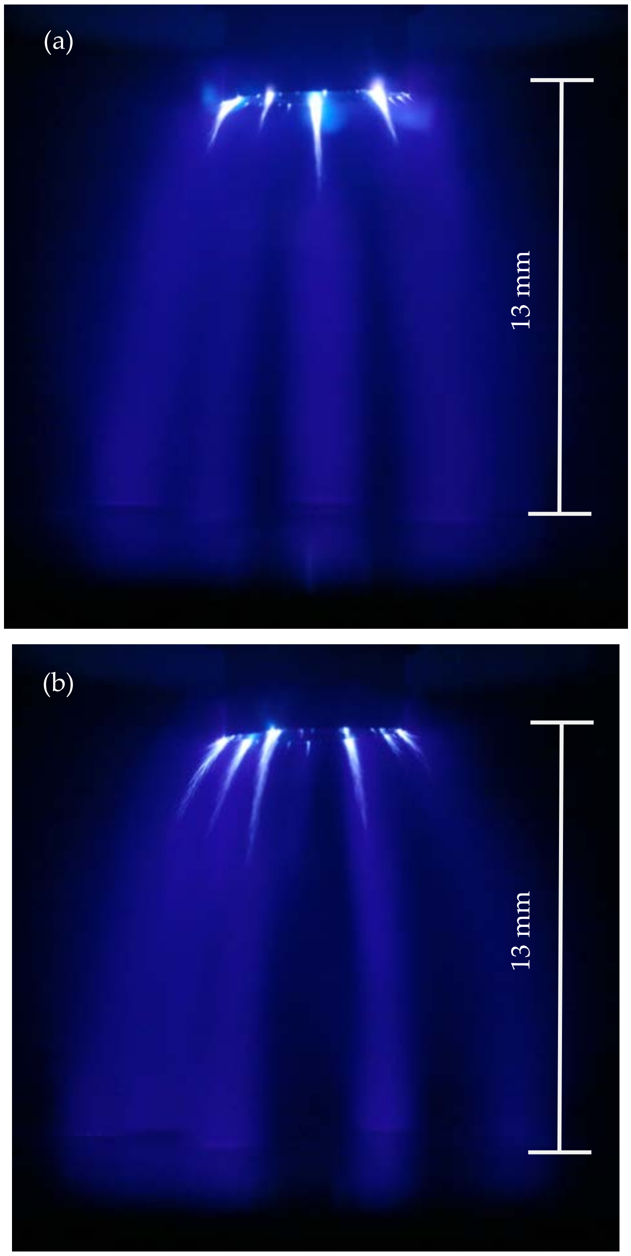

FIG. 4 DISCHARGE IMAGES WITH NEGATIVE (a) AND POSITIVE (b) POLARITY. NITROGEN PRESSURE IS 0.3 MPa. “TUBE-PLANE” CONFIGURATION

We consider, that the SAEB generation is caused by amplification of electric field at the electrode with small radius of curvature and in the gap due to amplification of electric field at the front of ionization wave that bridge the discharge gap.

At a positive polarity of RADAN-220 pulser SAEB wasn`t registered behind the cathode foil, but the X-ray was registered from the gap at the small interelectrode distance.

Waveforms of voltage pulses, current through gap, SAEB current and discharge plasma radiation pulse were registered at negative polarity of RADAN-220 pulser in all three gases at different pressure. The amplitude of SAEB decreased when the pressure increased. The smallest amplitude of SAEB was observed in heavy electronegative SF_6. However, REP DD was formed in SF_6 at both polarity (Fig. 5).

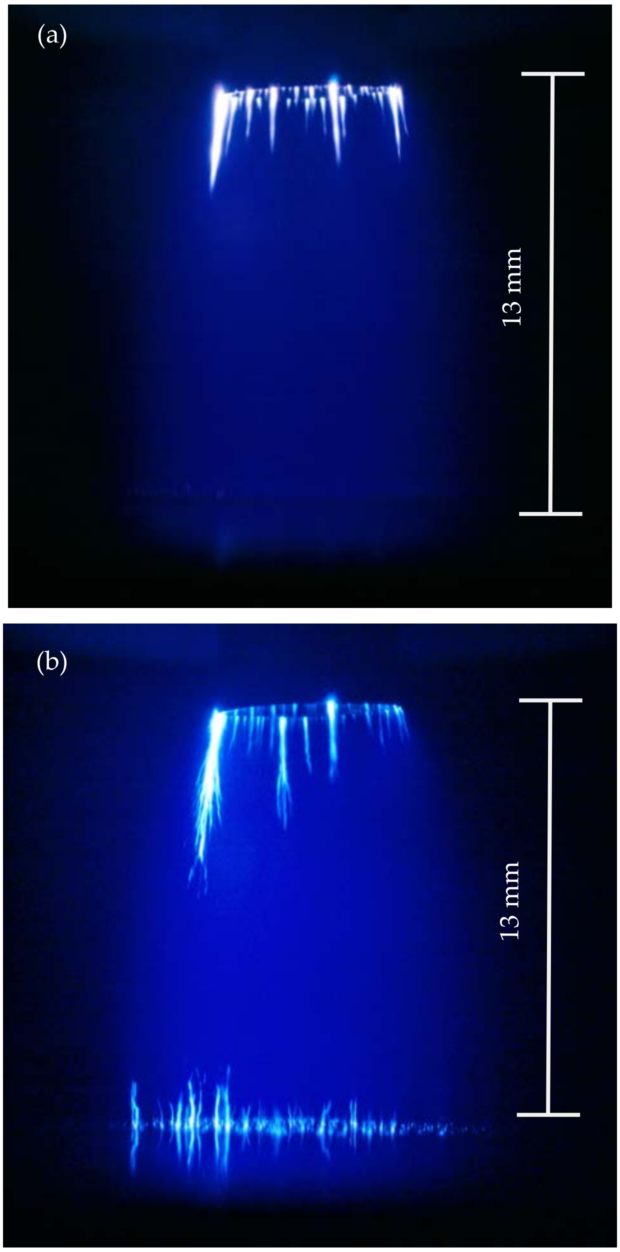

FIG. 5 DISCHARGE IMAGES WITH NEGATIVE (a) AND POSITIVE (b) POLARITY. SF_6 PRESSURE IS 0.05 MPa. "TUBE-PLANE" CONFIGURATION

It is seen, that the discharge has diffuse form, and on the electrodes bright spots with spark leaders growing from them are observed.

When we used "blade-blade" configuration REP DD was occured. Then REP DD transformed to a spark discharge (Fig. 6).

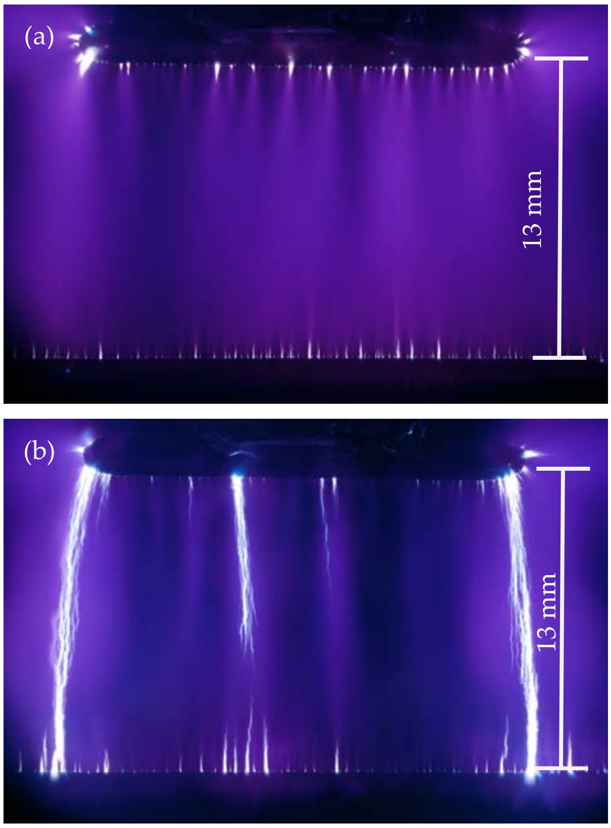

FIG. 6 DISCHARGE IMAGES WITH NEGATIVE (a) AND POSITIVE (b) POLARITY. NITROGEN PRESSURE IS 0.1 MPa. "BLADE-BLADE" CONFIGURATION

The form of discharge was depended on a polarity of high voltage pulses, pressure, kind of gas and electrode configuration.

The analyze of waveforms of the discharge plasma radiation pulses from different discharge regions shown that threshold level of radiation sufficient for registration is achieved earlier near the potential electrode. As is known, during the formation of breakdown, the highest intensity of electric field is realized near the potential electrode with small radius of curvature. In Fig. 7 the calculated with code ELCUT 5.1 Proffesional distribution of electric field for the tubular potential electrode is presented at the amplitude of high voltage pulse of 250 kV.

It is seen, that the intensity of electric field reaches 1.8 MV/cm near the tubular potential electrode. This value is sufficient, given of the influence of the cathode microrelief, for appearance of electrons due field emission.

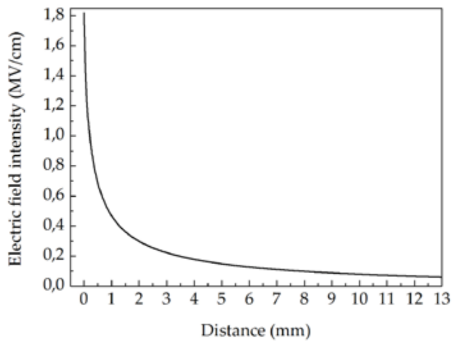

FIG. 7 DISTRIBUTION OF ELECTRIC FIELD IN THE GAP. "TUBE-PLANE" CONFIGURATION

The experiments carried out with the time resolution of ~0.1 ns shown that the breakdown developed due to formation of the dense diffuse plasma, which bridges the discharge gap. In Fig. 8 (a) and Fig. 9 (a) waveforms of the discharge plasma radiation pulse are presented at negative polarity of RADAN-220 pulser for "blade-blade" and "tube-plane" configuration respectively. In Fig. 8 (b) and Fig. 9 (b) the derivative of emission intensity of the discharge plasma radiation are presented for the corresponding waveforms in Fig. 8 (a) and Fig. 9(a). The observed decline (area I in Fig. 8 (b) and Fig. 9 (b)) ~0.5 ns later for cathode region is associated with a formation and passing of the ionization wave front.

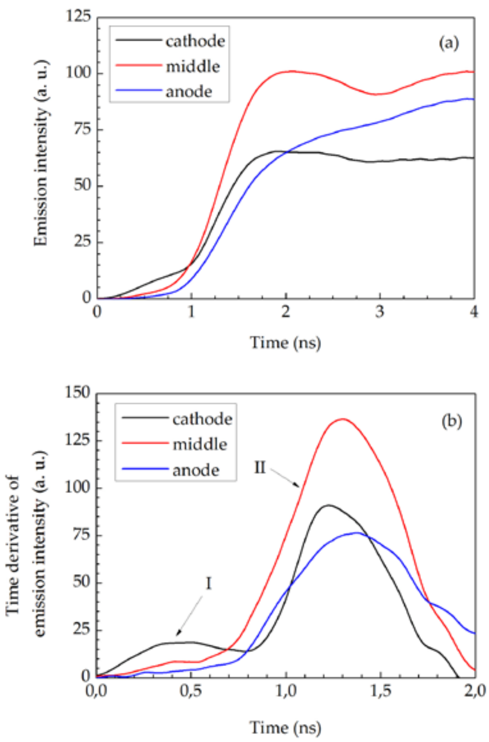

FIG. 8 WAVEFORMS OF EMISSION INTENSITY (a) AND THE DERIVATIVE OF EMISSION INTENSITY OF THE DISCHARGE PLASMA RADIATION (b) IN NITROGEN AT PRESSURE OF 0.7 MPa WITH NEGATIVE POLARITY. "BLADE-BLADE" CONFIGURATION

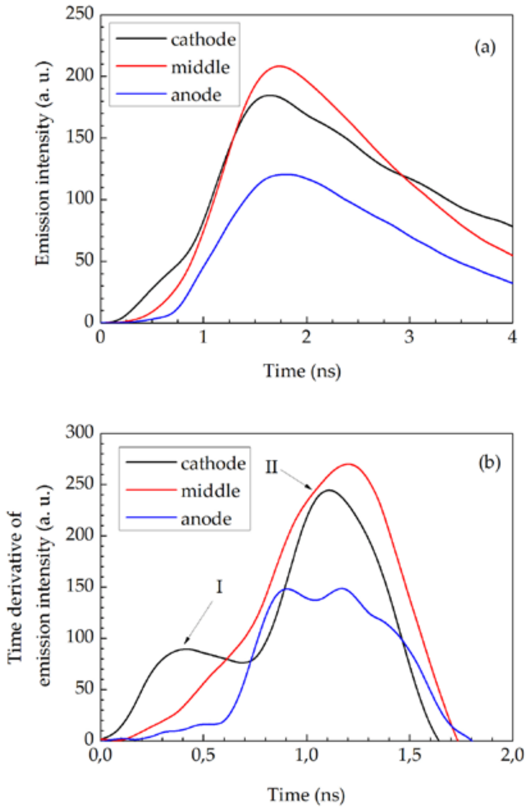

FIG. 9 WAVEFORMS OF EMISSION INTENSITY (a) AND THE DERIVATIVE OF EMISSION INTENSITY OF THE DISCHARGE PLASMA RADIATION (b) IN NITROGEN AT PRESSURE OF 0.7 MPa WITH NEGATIVE POLARITY. "TUBE-PLANE" CONFIGURATION

These features are observed in all used gases. Ionization wave velocity decreased at increasing pressure. The ionization wave velocity is less in heavy SF_6 than in air or nitrogen. In addition, at a positive polarity of the pulser the ionization wave velocity is more than at the negative polarity due to less blurring of the ionization wave front. At a negative polarity RAE ionize a gas ahead of the ionization wave front. The RAE can cross the discharge gap fully. Thus, RAE preionize the gas between the ionization wave front and the anode. This process leads to blurring of the ionization wave front and reduction of electric field intensity on a border of dense plasma. At a positive polarity RAE move to side of the dense plasma and anode with small radius of curvature. Thus, a preonized zone ahead the ionization wave front becomes smaller. It leads to increasing of the electric field intensity. As the result the ionization wave velocity increases. From the obtained data it is ensued that the ionization wave velocity is increasing when the ionization wave front approaches to anode. It is possible due to the fact that the electric field intensity is increasing and the concentration of initial electrons in the region between the ionization wave front and

the grounded electrode is increasing too by RAE, soft X-rays, VUV and UV which preionize this region.

Conclusions

The initial stage of breakdown in an inhomogeneous electric field in air, nitrogen and SF_6 at high pressure is investigated. With the time resolution of ~0.1 ns the dynamics of the discharge plasma radiation from different regions of discharge gap was obtained synchronously with the voltage across the gap, discharge current and SAEB current. It was shown that the breakdown is occurred owing to the ionization wave, which starts from a electrode with small radius of curvature at both polarity of high voltage pulses. It was determined that the ionization wave velocity decreases with increasing pressure of gases from 0.05 to 0.7 MPa. In heavy SF_6 the ionization wave velocity is less than in air and nitrogen. The SAEB was registered in air, nitrogen and SF_6.

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